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# The impact of manual light switching on lighting energy consumption for a typical office building

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## ABSTRACT

This paper presents a study about the potential energy savings due to manual switching of lights (at half power) for one floor of a medium-size office building in Chicago. The office is separated in perimeter and core zones and hourly interior daylight levels were initially calculated for each zone. Previously developed behavioral models were used to compute the expected lighting “switch-on” and “switch-off” probability functions (manual operation). The percentages of people switching lights was input to a daylighting and energy model, which predicted occupant-area averaged resulting hourly work plane illuminance values for each zone. Based on these results, the potential annual energy savings from manual on/off switching of lights (at half power) was calculated for interior and core zones. The results showed that savings with manual switching can be substantial (>40%) even for darker interior zones, which could be an advantage compared to automatic lighting control.

## 1. INTRODUCTION

Lighting control can result in significant energy savings, especially in commercial buildings with large glass facades. With automated systems, lights should turn off or dim at a lower level when the available natural light on the work plane exceeds a pre-determined target value (usually around 500 lx). However, the occupants' involvement is neglected in available simulation tools and energy calculations. Occupants tend to override automated systems and change their luminous environment without necessarily following a specific pattern. Occupant switching behavior is complicated and it depends, except for the individual personality, on the available daylight, time of the day, type of electric lighting, type of switch and location relative to the closest windows.

Recent studies have dealt with the problem of identifying occupant light switching preferences (Nicol *et al.*, 2006). Some of these studies focused on predicting the probability that people will switch lights on or off (Boyce *et al.*, 2006, Lindelof and Morel, 2006). This paper uses some of the manual switching probability functions to estimate potential lighting energy savings in a typical office space. The next section present the method used and the calculated results.

## 2. CALCULATION METHOD

### 2.1 Building description

The building layout is presented in Figure 1. There are perimeter zones and core zones, as well as conference (meeting) rooms in two corners. Occupants seated near the perimeter experience higher exposure to daylight and therefore the switching probability will be higher. People seated in the core of the building have limited access to daylight and therefore switching off lights is less frequent. The office consists of cubicles (individual workstations) in the perimeter and in the core zones, and there is an open area on the south side (main entrance zone). The total office space is 900 m<sup>2</sup>, from which 310 m<sup>2</sup> are perimeter zones, 390 m<sup>2</sup> are interior zones and 200 m<sup>2</sup> are corridors and general use spaces. The work schedule is from 8am to 6pm.

The walls are occupied (70%) by windows (double glazed with a low-emissivity coating) and normal transmittance equal to 30% (this value represents a medium-tinted glass or a shading device to simulate realistic situation –if the

windows are more transparent, the energy savings will be higher than those presented in this study). Lighting was modeled as series of T-8 fluorescent lamps (2' x 4'), in all workstations. In order to achieve 450 lux on the work plane, the average lighting power density was 13.5 W/m<sup>2</sup>. The electric lighting design was done using the Flucs Pro module of IES-VE<sup>®</sup> software (2008). The method followed consists of the following steps:

- Prediction of work plane illuminance (natural light) on each hour of the year
- Calculation of people (%) switching on/off lights using behavioral models
- Calculation of occupant-area averaged lighting energy use with manual switching for perimeter and core areas
- Calculation of the potential energy savings due to manual light switching

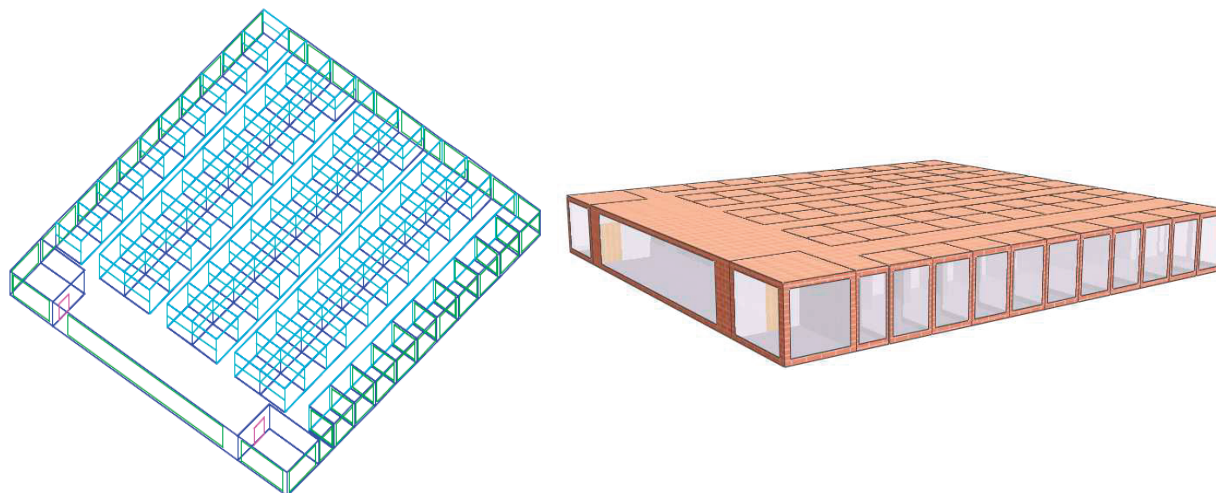


Figure 1: Schematic of space layout and office floor.

## 2.2 Prediction of work plane illuminance (daylight) in all spaces

Daylight levels was calculated based on the Perez all-weather sky model (Perez *et al.*, 1992), using the TMY2 weather data for Chicago. The model uses the hourly climatic data to calculate hourly direct and diffuse solar radiation on each tilted (vertical) surface of the building, and then hourly illuminance on the exterior is computed from the Perez luminous efficacy models, which take into account anisotropic sky distributions throughout the year. Daylight transmission in each of the spaces was calculated using the window optical properties. Finally, natural light levels on a pre-selected grid on the work plane (at 0.85m from the floor) were obtained by using the advanced ray-tracing technique of the software which is based on Radiance<sup>®</sup> software (LBNL, 2000). This method takes into account reflected light from all surrounding surfaces and transmitted light through openings (above cubicle separators) into other adjacent rooms. Hourly daylight values are needed to calculate the total lighting levels in each space (including electric lighting) and input this information in the probabilistic models for occupant behavior, as explained below. An example of work plane illuminance distribution in all perimeter zones on March 21<sup>st</sup> is shown in Figure 2.

Due to the large number of data (8760 hours in the year for each space), a monthly average was calculated for each hour of each month, using the simulation results for the perimeter zones and the core zones separately. Figure 3a shows the averaged natural lighting levels for the perimeter zones: the vertical axis is the hour of the day and the horizontal axis is the month number (Jan-Dec). Higher daylight levels are observed around noon, and around summer and shoulder seasons, as expected. Figure 3b shows the respective results for the interior (core) spaces, which are of course exposed to less natural light (the highest daylight levels in the core reach 120 lux in the summer around noon).

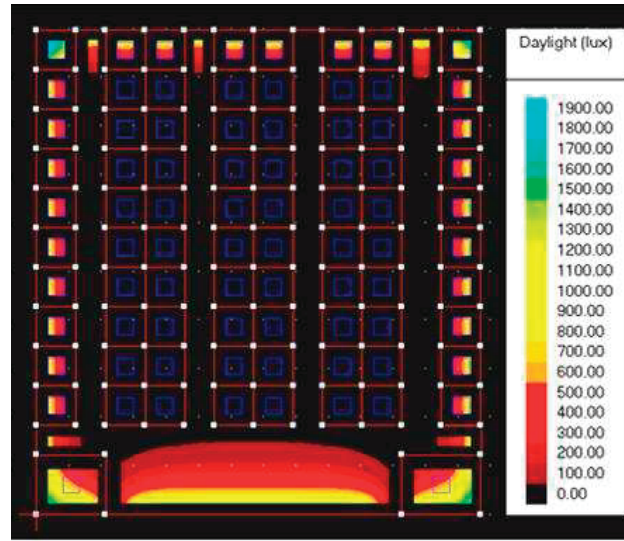


Figure 2: Daylight levels on the work plane of perimeter zones (March 21<sup>st</sup>, noon).

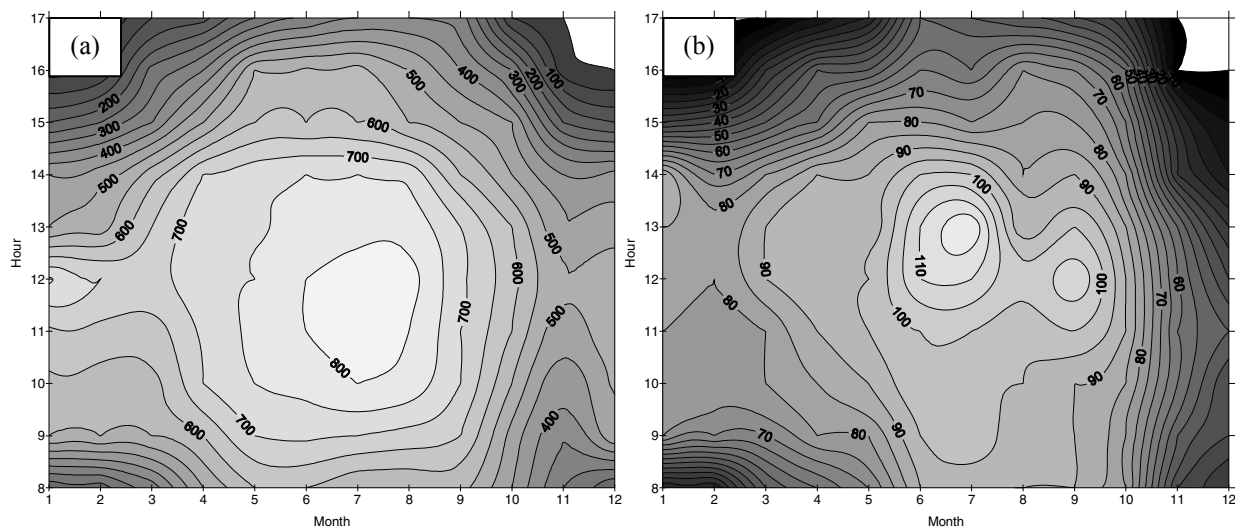


Figure 3: Yearly-averaged hourly daylight levels for (a) perimeter zones and (b) interior zones

### 2.3 Behavioral patterns and calculation of percentage of people switching on/off lights using probabilistic models

The first study of behavioral patterns of occupants interacting with lighting systems was by Hunt (1979). The switch-on probability (probability of people switching on electric lights) was computed as a function of minimum work plane illuminance. During the last decade, a few studies focused on manual lighting operation and intermediate switching (Love, 1998; Maniccia *et al.*, 1999; Reinhart, 2003, 2004; Lindelof and Morel, 2006; Boyce *et al.*, 2006) with useful projections for prediction of potential energy savings. Figure 4 presents the lighting switch-on probability (blue triangles) based on the results by Hunt (1979). Exponential regression ( $R^2=0.98$ ) was used to approximate the curve (red line) and produce Eq. (1) below that could be used in simulation model for computing the percentage of people switching lights on (at arrival and hourly thereafter) as a function of work plane illuminance:

$$\% \text{ switch OFF} = 1.065 \cdot e^{-0.0071 \cdot WPI} \quad (1)$$

where  $WPI$  is the work plane illuminance.

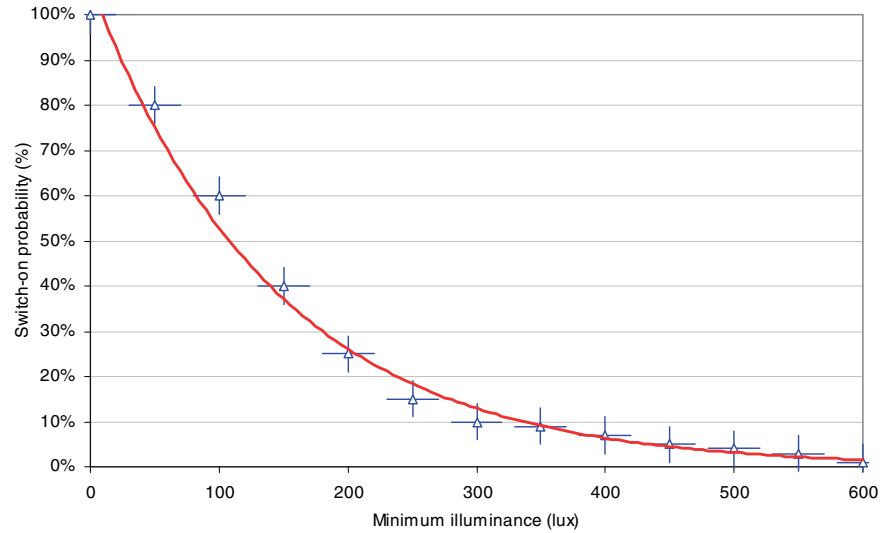


Figure 4: Lighting switch-on probability (blue points) based on the study of Hunt (1979) and regression curve (red line) described by Eq. (1) and used in the model.

For the simulation model, it is necessary to also calculate the lighting switch-off probability. Assuming that the lights will be on by the time of arrival, a switch-off probability function will compute the percentage of people who would switch lights off, depending on the available natural light levels. Boyce *et al.* (2006) conducted a field experimental study with more than 33 people in individual workstations and calculated the switch off probability (data points with error bars every 100 lux bins) as a function of work plane illuminance (blue points shown in Figure 5). This data was approximated with a 5<sup>th</sup>-degree polynomial so that Eq. (2) could be used in simulation model for computing the percentage of people switching lights off (at arrival and hourly thereafter) as a function of work plane illuminance:

$$\% \text{ switch OFF} = -5.885 \cdot 10^{-14} \cdot WPI^5 + 1.511 \cdot 10^{-11} \cdot WPI^4 + 6.493 \cdot 10^{-8} \cdot WPI^3 + 2.273 \cdot 10^{-6} \cdot WPI^2 + 1.615 \cdot 10^{-8} \cdot WPI \quad (2)$$

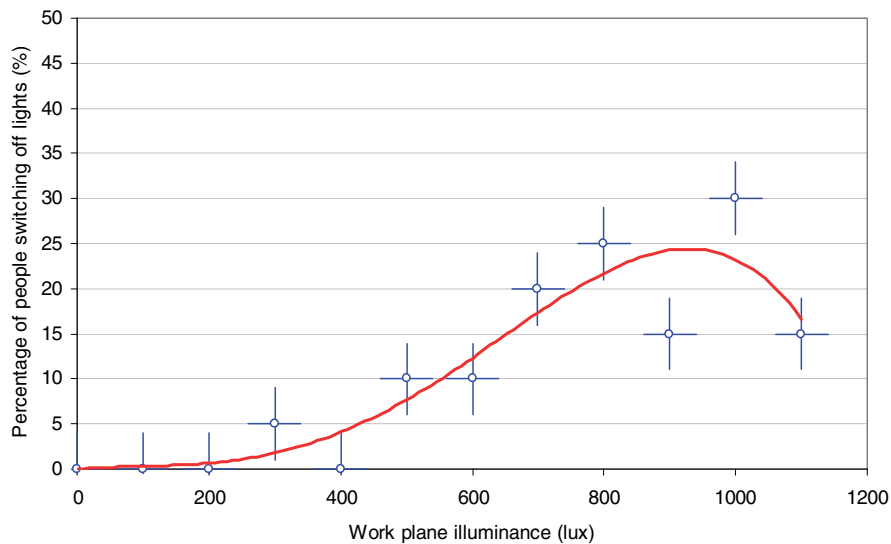


Figure 5: Lighting switch-off probability (blue points) based on the study of Boyce *et al.* (2006) and regression curve (red line) described by Eq. (2) and used in the model.

## 2.4 Calculation of occupant-area averaged lighting energy use with manual switching for perimeter and interior zones

The switch-on and switch-off probability functions were used to predict the resulting work plane illuminance in the perimeter and core areas (separately) as follows. First, the average natural light levels are input in the model. At 8am (arrival time), all the lights are assumed to be 50% on (using a lighting management system), so the additional  $450/2=225$  lux from electric lighting are added to the natural light levels, to calculate the total (natural and artificial) lighting levels on the work plane (note that this assumption could essentially determine the magnitude of energy savings as explained later). These total lighting levels are then used in the switch-on and switch-off probability functions, to estimate the percentage of people who would switch lights at 100% power or switch off lights within that hour respectively. If  $x\%$  switch lights on (at full power), and  $y\%$  turn lights off, then  $(1-x-y)\%$  will keep the lights at 50% power. The realistic lighting levels during the next hours are computed by taking into account the actions during the previous times.

The resulting distribution of occupants switching lights on or off is equivalent to the distribution of average illuminance at 9am in each space, considering the change in lighting levels when lights are switched. In other words, the work plane illuminance at 9am is equal to the available daylight at 9am plus the electric lighting levels which are calculated based on the percentage of people switching lights on (electric lighting levels at 450 lux), the percentage of people switching lights off, and percentage of people who did not change electric lighting levels (remaining at 225 lux) at 9am.

Based on the computed work plane illuminance at 9am, the switch-on and switch-off probabilities are calculated based on the natural illuminance distributions at 10am and the process continues for each hour in the day, for the 12 months, separately for perimeter and interior zones. The model takes into account the percentage of people who switch lights from 0 to 50%, from 50% to 100%, as well as switching from 100% to 50% and from 50% to zero for each hour.

## 3. RESULTS

### 3.1 Switching on/off probabilities

Based on the analysis, the average percentage of people switching lights on, off, or not changing electric lighting levels for each hour in the year are shown in Figure 6 for the perimeter zones and the interior zones respectively. Note that a significant percentage of people will not change lighting levels even in interior zones –this is a key point for realization of energy savings with manual lighting operation.

### 3.2 Potential energy savings due to manual switching of lights

Based on the above results, the lighting energy use is calculated as the weighted average of the percentage of switched-on, switched-off and maintained-level lights in each area for each hour. The lighting energy savings (compared to no lighting control) are due to the percentage of people who (i) do not turn lights at full power because they are relatively comfortable with natural light levels plus lights at 50% power, and (ii) switch lights off depending on available natural light. These percentages are multiplied by the respective areas and by the total number of hours in the year. Figure 7 shows the respective energy savings from manual light switching in perimeter and interior zones. Savings reach 57% for perimeter zones and 45% for interior darker zones, resulting in area-averaged savings of 50% for the entire floor.

The energy savings using manual switching for the perimeter zones, the interior zones and the entire floor are summarized in Table 1. The results are also compared with theoretical automated stepped lighting control, which assumes that lights are dimmed to 50% when natural lights levels exceed 500 lux. The savings using manual switching are higher for two reasons:

- I. It was assumed that the lights are at 50% power at arrival. Due to the fact that a large percentage of people will not switch lights on or off (because daylight levels are satisfactory), the intensity will remain at 50% even for illuminance values lower than 450 lux and this results in energy savings, especially during times with low natural light levels. If the lights were 100% on at arrival, then the savings with manual switching would be lower because most people would not switch them to 50% (or completely off); however, an automatic control system would reduce lighting levels in this case.
- II. Especially for the interior zones (which receive much less natural light and are a big part of the building), the percentage of people not switching lights on contribute to high energy savings. However, these zones would remain darker than normal and, depending on the space use, this might cause problems.

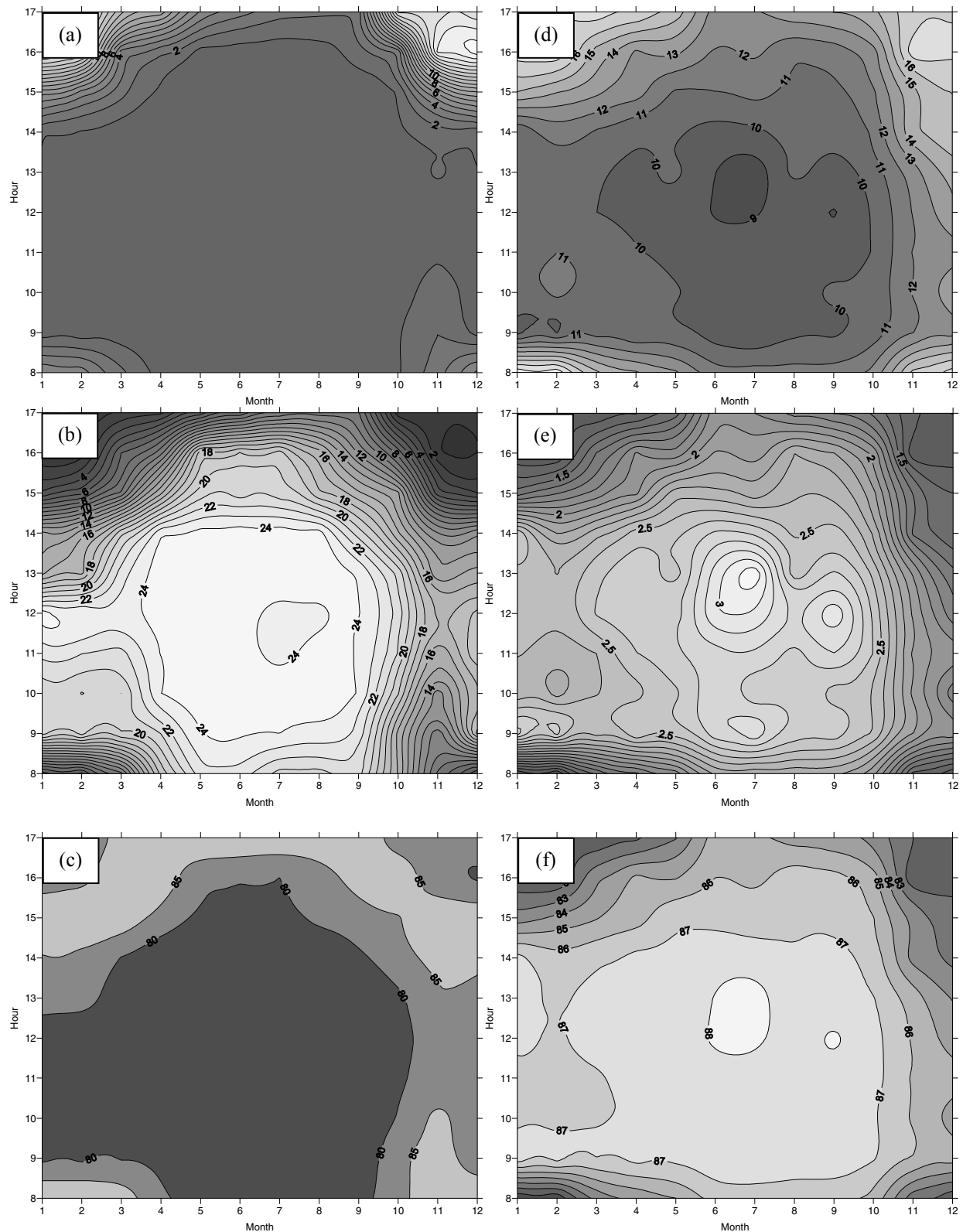


Figure 6: Percentage (%) of people hourly switching lights on (a), off (b), and neither on or off (c) for perimeter zones and switching lights on (d), off (e), and neither on or off (f) for interior zones respectively.



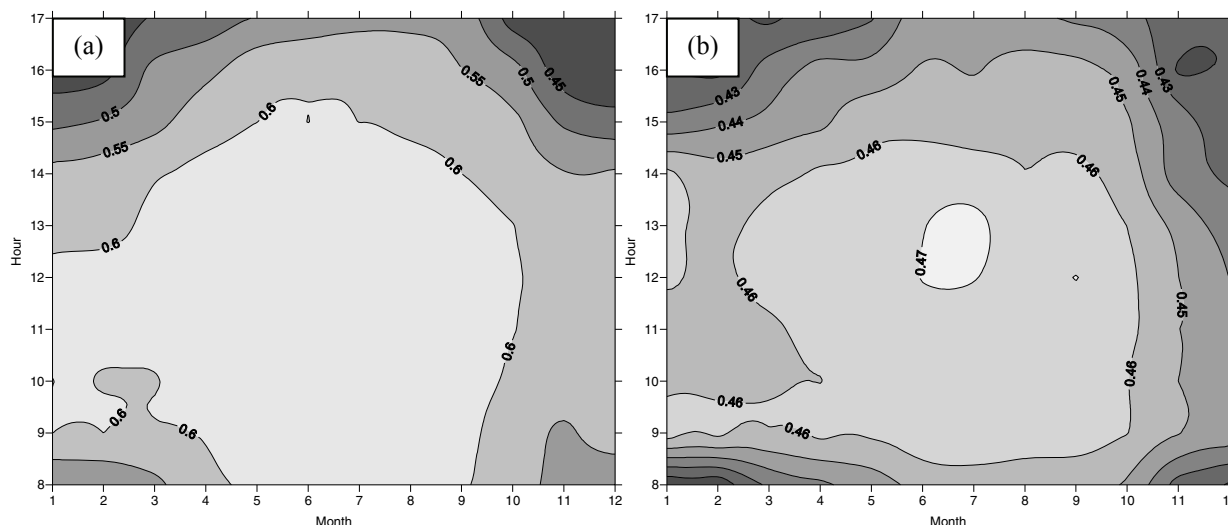


Figure 7: Energy savings due to manual light switching throughout the year for perimeter (a) and interior (b) zones. Values are percentages (i.e., 0.5 = 50% savings).

Table 1: Comparison of annual lighting energy and energy savings for different zones and control modes

	<b>Perimeter zones</b>	<b>Interior zones</b>	<b>Entire floor</b>
Annual lighting energy consumption (no controls/switching) (kWhrs)	11457	14414	25871
Annual lighting energy consumption (manual switching) (kWhrs)	4905	7915	12820
Annual lighting energy consumption (automatic stepped control) (kWhrs)	8689	14414	23103
Energy savings (manual switching) (%)	57%	45.1%	50.3%
Energy savings (automatic stepped control) (%)	24%	0%	10.6%

## 4. CONCLUSIONS

A simulation model for predicting energy savings due to manual light switching (0, 50% and 100% power) for a typical office building floor was presented. The space was separated in perimeter and core zones for differentiation of the results and better understanding of where the energy savings come from. Previously developed behavioral models for probabilistic light switching were used in the analysis. The percentage of people switching lights on/off was input to the lighting/daylighting model, which predicted occupant-area averaged resulting hourly work plane illuminance for each zone throughout the year. Assuming that the lights will not be a full intensity at arrival time, the probabilistic models showed that a significant percentage of people will not switch lights on, therefore contributing to reduced lighting energy use in perimeter and interior zones (57% and 45% respectively) compared to automatic stepped dimming control. However, the results are sensitive to the initial setting of light intensity at arrival. Considering the potential low price of the switching system, the manual switching system is an attractive option. Note also that the impact of shading was not considered in this analysis; it will have an impact on the interior lighting levels and on the occupants' response to light switching. A combination of a stepped switching system with a light dimming strategy in different zones could result in maximized energy savings while satisfying occupant preferences.



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